CARTOGRAPHIC COMPARISONS OF EURASIAN GYPSY MOTH DISTRIBUTION (*LYMANTRIA DISPAR* L.; LEPIDOPTERA: LYMANTRIIDAE)[1]

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ABSTRACT: Historic maps have been reconstructed to a common scale and projection in order to compare Eurasian distribution of the gypsy moth. Sites from the early studies were used, along with new information, to produce 2 new versions of the moth's Old World range. One "modern" map displays locations of documentable reports of gypsy moths. The second presents contoured zones of presence and outbreak. These zones are much more constrained than on the historic maps due to strict contouring conventions. The largest area of periodic outbreak occurs between 0-50°E longitude and 40-55°N latitude. The major area of distribution is typified by an annual precipitation of at least 10 cm, and July and January average isotherms of 15 to 27°C and -18 to 12°C, respectively. Outbreak areas, however, typically receive 25-100 cm of annual moisture. As it relates to climate and vegetation, a more accurate picture of gypsy moth distribution in the Eastern Hemisphere will aid current investigations pertaining to the moth's spread and establishment in new areas in North America; new information will also aid in the search for exotic natural enemies of this pest.

The gypsy moth, *Lymantria dispar* L., has been present in North America for over a century. For many years this pest was confined to the northeastern United States, but changing practices of pesticide usage, natural dispersal, and inadvertent transport on vehicles have resulted in an extended geographic range of the gypsy moth in this country and Canada. It seems clear that containment is no longer possible and a large range expansion on this continent can be anticipated. Just where, and at what rate, establishment in new areas will occur are subjects of current concern.

One important base of information is the historic distribution of the gypsy moth in Eurasia, the source of this introduced species. Knowledge of vegetation, climate, and physical features can provide a necessary backdrop for current investigations dealing with genetics, biological control, population dynamics, and bioclimatology of the gypsy moth. Several of the major historic investigations of gypsy moth distribution over large land areas are written in different languages, and are not commonly available in this country. Though these works contain distribution maps constructed from each author's own sources and data interpretations, direct comparisons are not possible because of differences in map projections and scales. To bring together the valuable information contained in these studies, the maps have been redrafted to a common scale and are presented herein in comparable forms, along with pertinent information gleaned from the translated articles. In addition, new maps have been synthesized to display both specific locations of the gypsy moth, and generalized areas classified as to presence and known outbreaks.

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MATERIALS AND METHODS

For more convenient comparison, 4 maps derived from the literature were redrafted such that each contained a common scale and projection. All original figures were redrawn onto computer-generated outline maps using the Miller Cylindrical projection with a scale of 1:18,750,000.

Locations for distribution points in Fig. 3 were obtained from a variety of literature and personal communication sources; the specific citations pertaining to individual countries are provided in Table 1 for workers interested in more local phenomena. Locations for gypsy moth presence and outbreaks were accepted from primary and secondary sources when, in the authors' judgement, the information was believed reliable. As used in this paper, "outbreak" denotes a mass appearance of the gypsy moth, as reported in the literature, which causes widespread defoliation. "Presence" denotes an endemic population for which no record of a mass appearance was found. "Distribution" and "range" imply the geographic area occupied by the gypsy moth. Within this area, moth populations may or may not periodically reach outbreak proportions.

The generalized classification map (Fig. 4) was configured using the following conventions:

- –When a zone, either outbreak or presence, constituted "contiguous points" $<5^\circ$ from each other, $.5^\circ$ was added to the outer bounds, and points were connected by smoothing.
- –When a continental boundary lay $\leq 2^\circ$ from a contour line plotted by the $.5^\circ$ criterion (as above), the zone was extended to that boundary (e.g., eastern England; northwestern France).
- –When an "odd" point fell within a zone (e.g., a presence point in an otherwise outbreak zone), it was simply included in that zone if surrounded by the predominant points by $\leq 3^\circ$ (e.g., presence point in western Portugal)
- –When an outbreak and a presence zone were within 2° of each other, the contour was drawn at the midpoint.
- –When the zones were defined by points $>2^\circ<5^\circ$ apart, the outbreak zone took the $.5^\circ$ criterion and the presence zone was extended to the outbreak contour.

- When at least 5° separated any 2 clusters of points of the same type, the corresponding zone was broken according to the first criterion, and the points were considered nonconterminous.
- When a known point fell $\geq 5°$ from any other point, it was plotted according to type and location, but was not included within a contoured zone.
- Major bodies of water were excluded from the zones; however, no attempt was made to exclude montane or desert areas if the general region met the above criteria, even though altitude or absence of hosts might preclude gypsy moth populations.

RESULTS

General Distribution According to Schedl

As far as could be determined, the first generalized map showing Eurasian distribution was published by Schedl in 1936. His records were assembled from both museum specimens and literature sources, and his paper documented numerous presence and outbreak locations. Distribution was shown to cover most of Europe north to 58°N, and south to the northwestern coast of Africa. In eastern Asia, the northern range extended to 52°N, and south to 20°N (Fig. 1A).

General Distribution According to the Commonwealth Institute of Entomology

The most recent transcontinental distribution map available was published 25 years ago (Anon. 1953) (Fig. 1B). Except for England which was not included, the northern range boundary almost everywhere exceeded that of Schedl, while the southern boundary in northern Africa was similar. Eastwards, the limit penetrated further south at most locations. The Commonwealth Institute employed the following criteria for contouring: (1) A broken line was used where the limit was not known. (2) When an area in which the pest was believed absent was surrounded by territories known to be infested, the former area was entirely shaded. Hence, the Gobi desert region was included in the distributional area, but the large arid area in Asia north and east of the Caspian Sea was left blank.

Classified Distribution According to Kozhanchikov

In his book on the tussock moths, Kozhanchikov (1950) considered the distribution of gypsy moths in the Old World. His map (Fig. 2A) indicated presence from Portugal in the west, conterminously to the main Japanese islands in the east. In Europe and North Africa, presence was between 32-61° north latitude; in the Far East, distribution lay between 24° and 56°N. Four outbreak regions were distinguishable within the larger distribution area:

(1) an area in northern Africa above the Atlas mountains; (2) the largest area, covering most of Europe, where the gypsy moth was characterized by population densities and outbreak frequencies greater than in the other regions; (3) an elliptically shaped area in central Asia, including portions of the Tien Shan, Altai, and Sayan Mountain ranges; and, (4) a region in the Far East bordering the Sea of Japan.

Classified USSR Distribution According to Kelus

Although national in scope, the work of Kelus (1941) covered such a large fraction of the gypsy moth range in Europe and Asia that it merited inclusion for comparison with the cross-continental studies. The USSR range shown by Kelus included all shaded areas in Fig. 2B and conformed, in general, with the outer boundaries depicted by Kozhanchikov (1950) within the USSR, though not so far north. Between these outer limits, Kelus showed the range protruding farther south into the semi-arid Siberian lowland area between 60° and 85°E longitude. In European USSR, the northern boundary of the gypsy moth was associated ". . .in its entirety with the area of the oak and does not go beyond the limits of this area" (Kelus 1941). In the Urals and western Siberia, the northern boundary coincided with the northern range of the lime tree (we assume *Tilia cordata* Mill.); in the Far East, the northern limit followed maple.

Kelus separated his distribution information into 3 classifications: presence, outbreak, and possible outbreak. The area identified as outbreak (Fig. 2B) was the zone where mass increases appeared at 8-12 year intervals. In this zone, there was "persistent damage done by the gypsy moth" and its boundaries coincided with the "area occupied by oak." It comprised a large fraction of the European part of the USSR, including the Crimean peninsula. This zone encompassed the entire forest steppe, the region of broadleaved forests, and, to a certain extent, the coniferous-broadleaved forest area.

The "possible outbreak" areas were demarcated as potential zones of increase. Although Kelus established these 7 areas largely according to climatic and vegetative criteria, he did document outbreaks within each area, except the most eastern. Outbreaks in these potential zones tended to be less frequent and occurred in fewer locations.

A Modern Synthesis of Classified Eurasian Distribution

Locations of gypsy moth presence and sites of historic outbreaks (Fig. 3) were documented from a wide variety of world literature and personal communications (Table 1). Besides Schedl (1936), Kozhanchikov (1950), and the Commonwealth Institute (Anon. 1953) whose maps and articles were used extensively, several other authors provided considerable international data: Burgess and Crossman (1929), Forbush and Fernald (1896), and Goldschmidt

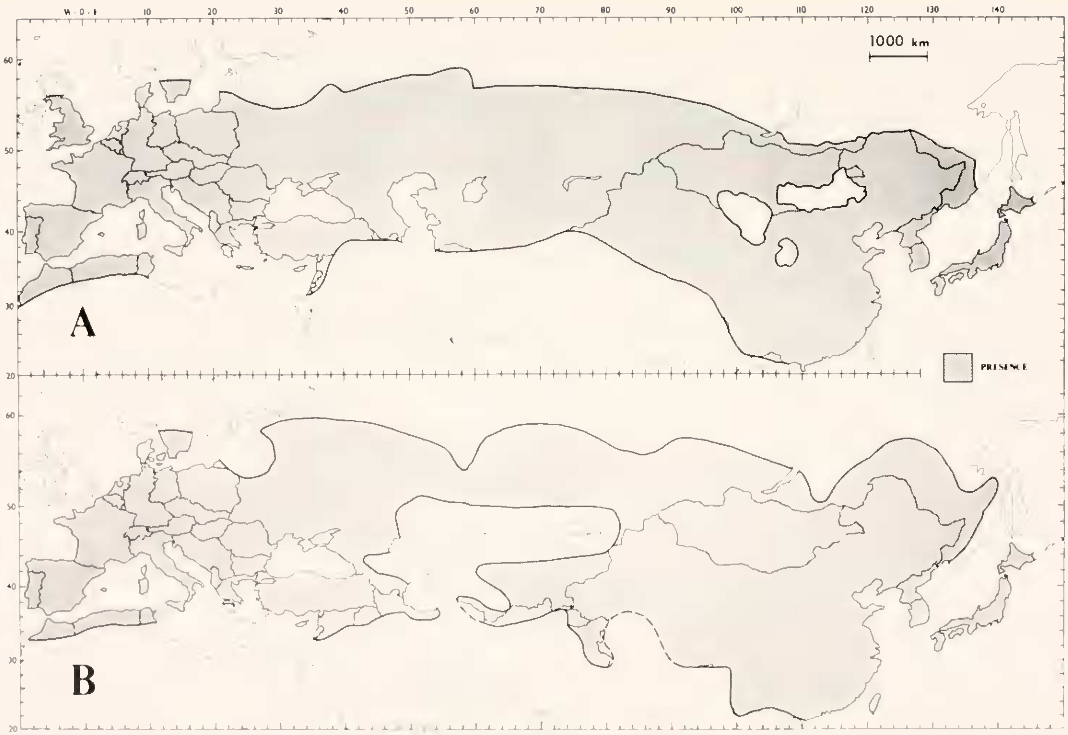

Fig. 1A – Eurasian gypsy moth distribution (redrafted from Schedl 1936).

Fig. 1B – Eurasian gypsy moth distribution (redrafted from the Commonwealth Institute of Entomology (Anon. 1953)).

(1934). The frequency of these names in Table 1 is not necessarily a reflection of their contributions, since any outbreak/presence location may have been reported by more than one source. In such cases, the most recent publication was listed in the table. Although the density of points in some countries could have been multiplied greatly (e.g., Yugoslavia), presence or outbreak as a classification was minimally satisfied when an outbreak site (or presence, as a last resort) was determined for a county, province, or similar intra-national division.

Zones of outbreak or presence were established using clusters of points joined according to the criteria given in the methods section. The resulting map (Fig. 4) shows the major areas the gypsy moth is known to inhabit, and those regions where outbreaks have been recorded. While there is good conformance of upper and lower bounds with previously published accounts, the new map is much more constrained internally due to the more rigorous criteria applied to zoning.

The northern limit at Leningrad (60°N 30°E) decreases eastwardly until, at 130°E, the northern range has dropped to 50°. Though more irregular, the southern limit also has a southerly trend toward the east. In Europe and North Africa the lower boundary is 30-32°N, while in the Far East (110°E) the gypsy moth is found down to 20°N.

Two large zones of outbreak occur west of 50°E. The first encompasses Europe and the Mediterranean, including most adjacent mainland areas and all major islands except Cyprus. The second covers eastern Europe and western Asia. Most of the area classified as outbreak is found between 0-50°E longitude and 40-55°N latitude. Though other disjunct outbreak zones appear throughout the range, it is this primary zone in western Eurasia where outbreaks are the most frequent and widespread. Because of the remoteness of the territory to the east of the 50th meridian, outbreaks are less likely to be reported than in Europe. Smaller secondary outbreak areas are also discernible: (a) the Tien Shan area south and southwest of Lake Balkhash; (b) the Altai-Western Sayan region north of 50°N; (c) an area surrounding western Lake Baikal; and, (d) several areas adjacent to the Sea of Japan.

The range boundaries in the upper regions of the Baltic and North Seas are open to question, largely because historical records are not clear whether the moth was a periodic immigrant or an established forest pest. While Kozhanchikov (1950) showed gypsy moth presence in Finland, neither of the generalized maps (Figs. 1A, 1B) collaborated his information. In 1958, 9 male moths were trapped in southern Finland, but Mikkola (1971) determined that all were migrants originating most probably from the Ryazan area of the USSR (about 200-300km southeast of Moscow). Similarly, the only record of a gypsy moth in Denmark between 1960-1970 was a male adult interpreted by Kaaber and Nordgaard (1970) to be a migrant.

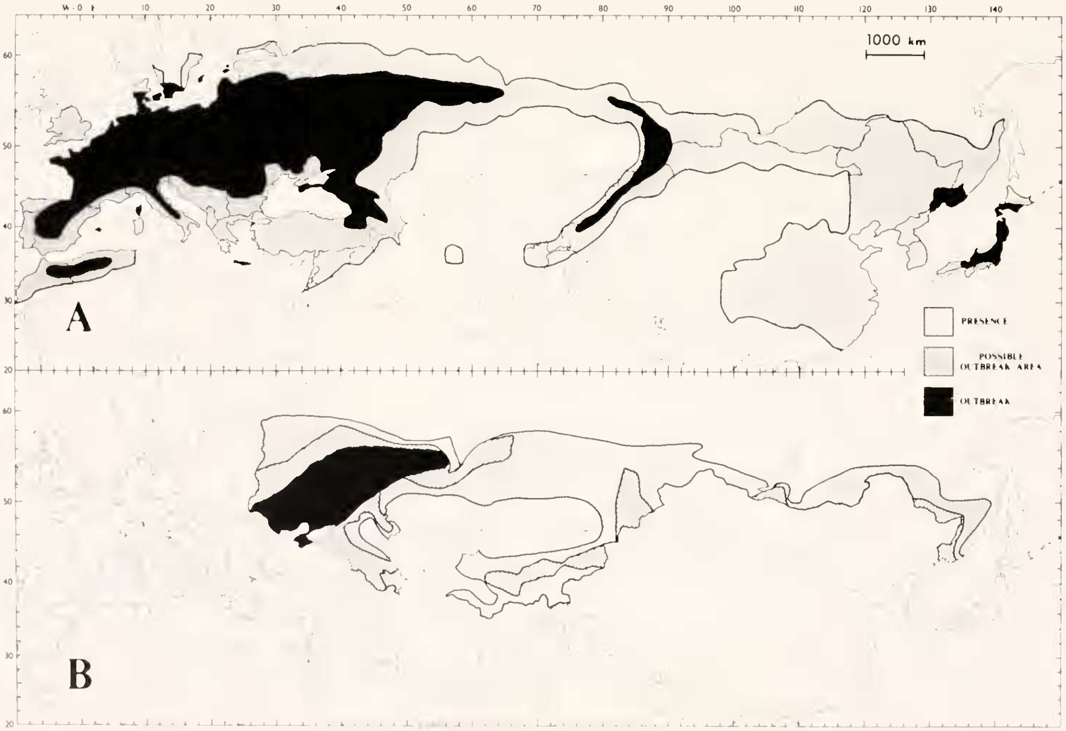

Fig. 2A – Classified Eurasian gypsy moth distribution (redrafted from Kozhanchikov 1950).

Fig. 2B – Classified USSR gypsy moth distribution (redrafted from Kelus 1941).

The distribution situation in England remains tenuous. While the gypsy moth was once found in Cambridgeshire, Huntingdonshire, and Buckinghamshire Counties, Kirby (1897) stated "It is now considered to be almost, if not quite, extinct as a British insect. . . ." Conveying information from the Natural Environment Research Council (Anon. 1975), a recent report noted the "apparently complete disappearance of the gypsy moth from the British Isles." Yet, Taylor[3] has provided presence records for 6 counties since 1961, plus the Scilly and Channel Islands.

In terms of the UNESCO classification of world ecosystems (Reichle 1973), primary gypsy moth distribution is found within the closed forest and open woodland, and to a lesser extent in the shrub regions. Within these larger classifications, distribution is confined chiefly to the following formations: cold deciduous forest, southern mixed forest, cool mixed forests and woodlands, and the southern boreal; lesser areas are found in dry woodlands and grasslands. Climatically, the area of distribution is represented mainly in the humid meso- and micro-thermal regions, but also, to some extent, in the dry steppe. Almost the entire range of gypsy moth distribution lies in areas receiving greater than 10 cm of annual precipitation; outbreak areas are typified by an annual precipitation of 25-100 cm. The intervals 15 to 27°C and -18 to 12°C, for the July and January average isotherms, respectively, coincide with most of the presence areas; however, outbreaks are usually confined to the intervals 15 to 23°C and -18 to 5°C for those months.

For visual purposes, broken lines are used to connect disjunct zones in Fig. 4. Although these must be regarded as unknown limits, they are roughly equivalent to the perimeters shown in Figs. 1 and 2.

Comparisons Between Modern and Historic Maps

Schedl's map (Fig. 1A) is in general agreement with the new map except that the latter exhibits areas beyond Schedl's northern boundary at longitudes 30° and 110°E. Elsewhere, the new range is normally included within that shown by Schedl. The Commonwealth Institute of Entomology map (Fig. 1B) is much more expansive than the new one, although good general conformance is seen at the frontiers. In both the Schedl and Commonwealth maps, Turkey is included in the gypsy moth's range, a phenomen we could document only in part. Likewise, a large, roughly rectangular trough on the new map—from 44°N to the Gulf of Finland, and varying longitudinally from 23° to 28°E—could not be confirmed.

On Kozhanchikov's map (Fig. 2A), the trough mentioned above was classified as outbreak area. The area adjacent to 34°E (between 52-58°N), also outbreak in Fig. 2A, could only be documented as presence on the current map. Reasonable coincidence is seen between the new map's boundaries and Kozhanchikov's, though between 30-60°E his northern limit

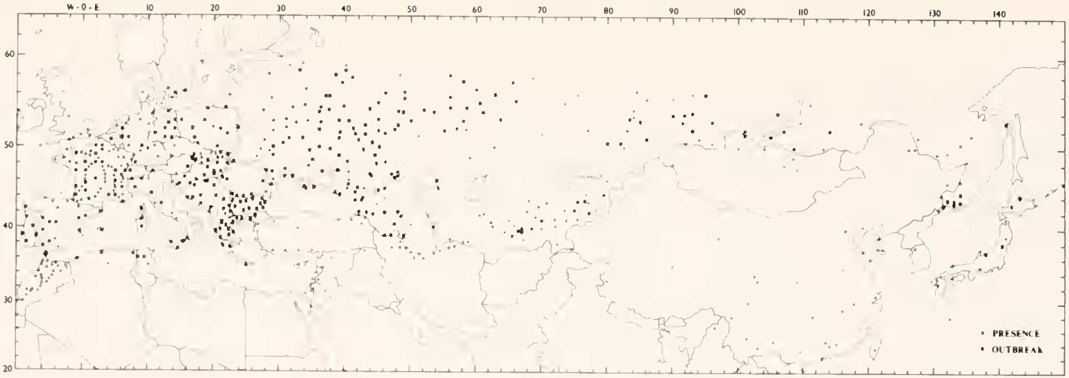

Fig. 3 – Sites of gypsy moth outbreak or recorded presence in Eurasia.

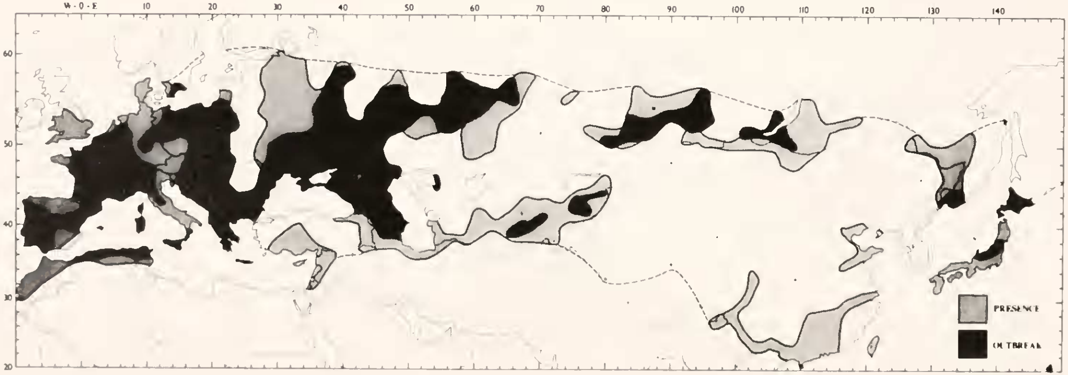

Fig. 4 – Zoned classification of Eurasian gypsy moth distribution (broken lines indicate unkown geographic limits). Individual points are presence (+) or outbreak (*) sites which did not fall within contoured zones.

goes to 63°N–4° higher than the modern map. Between the north and south boundaries, Kozhanchikov's distribution throughout Asia is more pervasive. A rather extensive elliptically shaped region which he classified as outbreak (between 40-55°N and 75-90°E) could not be confirmed on the modern map, except for a small area of agreement in the northwestern section. In other areas, the new map shows a larger outbreak zone in Portugal, and includes more Mediterranean Islands in the outbreak classification.

In the USSR (Fig. 2B), Kelus' range is generally more extensive than shown in the new map. Each area proposed as outbreak in the modern map coincides at least in part with areas he classifies as outbreak or possible outbreak.

Because of tighter constraints in constructing zones, the new map is generally more conservative than previous cartographic attempts. It is felt that incorporation of more recent information, along with more conservative classifications of zones, provides a more realistic basis for drawing biological inferences from geographic information. It would be helpful, of course, if results of gypsy moth research around the world were available from, or at least noted by, some central source. There are several areas, e.g., extreme western USSR (Estonia, Latvia, etc.), for which no gypsy moth information could be found. Considering the seriousness of this pest in nearby areas of Europe, it seems unlikely that knowledge through surveys or research is nonexistent, particularly when 3 of the 4 historic maps indicate the moth's presence. Yet, extensive literature searches and personal inquiries have yielded no information. It is hoped, however, that in spite of these limitations, the modern map may serve to aid and enlighten, in particular, those researchers seeking resolutions to the problems of gypsy moth range expansion in North America as well as those exploring for exotic natural enemies of this pest in the Old World.

Table 1. Sources of presence and outbreak data in Fig. 3.

EUROPE (excluding U.S.S.R.)

Austria
- Fuester et al., 1975
- Howard, 1905
- Howard & Fiske, 1911
- Pschorn-Walcher[4], 1978
- Ripper, 1933

Belgium
- Howard & Fiske, 1911
- Schedl, 1936

Bulgaria
- Chorbadzhiev, 1928
- Frydrychewicz, 1928
- Keremidchiev, 1972
- Mishin & Semevskii, 1971

Czechoslovakia
- Dominguez Garcia-Tejero, 1943
- Heskova, 1973
- Hochmut et al., 1974
- Hruby, 1964
- Schedl, 1936

Denmark
- Boas, 1923

EUROPE (excluding U.S.S.R.)–cont.

England
- Taylor[3], 1978

Finland
- Kozhanchikov, 1950

France
- Anon., 1953
- Brascassat, 1927
- Cadey, 1916
- Cointat, 1948
- Forbush & Fernald, 1896
- Grison, 1973
- Herard[8], 1978
- Howard & Fiske, 1911
- Schedl, 1936

Germany
- Cadey, 1916
- Forbush & Fernald, 1896
- Fuester et al., 1975
- Goldschmidt, 1934
- Howard & Fiske, 1911
- Mishin & Semevskii, 1971
- Schedl, 1936
- Schneider et al., 1974
- Skatulla[5], 1978

Greece
- Georgevits[6], 1978
- Isaakides, 1935
- Kailidis, 1962

Hungary
- Burgess & Crossman, 1929
- Frydrychewicz, 1928
- Hadzistevic & Hadzihalilovic, 1959
- Howard & Fiske, 1911
- Kiss et al., 1965
- Mishin & Semevskii, 1971
- Schedl, 1936

Italy
- Burgess & Crossman, 1929
- Goldschmidt, 1934
- Howard, 1905
- Howard & Fiske, 1911
- Mishin & Semevskii, 1971
- Muesebeck & Parker, 1933
- Nizi & Prosperi, 1973
- Prota, 1974
- Zwölfer, 1972

Netherlands
- Forbush & Fernald, 1896
- Howard & Fiske, 1911

Poland
- Forbush & Fernald, 1896
- Frydrychewicz, 1928
- Herard[8], 1978
- Karg, 1970
- Nunberg, 1925
- Schedl, 1936

Portugal
- Greathead, 1976
- Schedl, 1936
- Zerkowitz, 1946

Rumania
- Constantin, 1956
- Howard, 1905
- Howard & Fiske, 1911
- Marcu, 1970
- Pirvescu, 1964
- Simionescu et al., 1973

Spain
- Aullo, 1926
- Burgess & Crossman, 1929
- Dominguez Garcia-Tejero, 1943
- Forbush & Fernald, 1896
- Greathead, 1976
- Romanyk, 1973
- Schedl, 1936

Sweden
- Forbush & Fernald, 1896
- Lekander, 1951
- Schedl, 1936

Switzerland
- Schedl, 1936
- Zwölfer, 1972

Yugoslavia
- Frydrychewicz, 1928

EUROPE (excluding U.S.S.R.)–cont.

Georgijevic & Vaclav, 1958
Goldschmidt, 1934
Hadzistevic & Hadzihalilovic, 1959
Krnjaic, 1967
Maksimovic et al., 1970
Mishin & Semevskii, 1971
Pschorn-Walcher[7], 1978
Schedl, 1936
Vasic & Jankovic, 1959
Vasiljevic, 1959
Zwölfer, 1972

ASIA (excluding U.S.S.R.)

Afghanistan
  Anon., 1953

Burma
  Schedl, 1936

China
  Anon., 1953
  Forbush & Fernald, 1896
  Goldschmidt, 1934
  Kozhanchikov, 1950
  Schedl, 1936

Cyprus
  Anon., 1953
  Schedl, 1936

India
  Anon., 1953

Iran
  Adeli & Soleimani, 1976
  Anon, 1957
  Herard[8], 1978
  Kozhanchikov, 1950
  Schedl, 1936

Iraq
  Anon., 1953

Israel
  Anon., 1953
  Schedl, 1936

Japan
  Goldschmidt, 1934
  Masaki, 1956

Korea
  Goldschmidt, 1934
  Kozhanchikov, 1950

Lebanon
  Kozhanchikov, 1950
  Talhouk, 1950

Mongolia
  Kozhanchikov, 1950
  Schedl, 1936

Syria
  Schedl, 1936

Taiwan
  Anon., 1953

Tibet
  Anon., 1953
  Schedl, 1936

Turkey
  Anon., 1953
  Kozhanchikov, 1950

U.S.S.R.

Abdullaev, 1970
Benkevich, 1961a
Benkevich, 1961b
Benkevich, 1962
Bey-Biyenko, 1924
Burgess & Crossman, 1929
Edel'man, 1956
Forbush & Fernald, 1896
Frydrychewicz, 1928
Goldschmidt, 1934
Howard & Fiske, 1911
Kelus, 1941
Kondakov, 1963
Kozhanchikov, 1950
Mikkola, 1971
Mishin & Semevskii, 1971
Pantyukhov, 1962
Ryvkin, 1957

U.S.S.R.—cont.

- Schedl, 1936
- Vorontsov, 1968

AFRICA

Algeria
- Burgess & Crossman, 1929
- Kozhanchikov, 1950
- Schedl, 1936

Morocco
- Burgess & Crossman, 1929
- Herard[8], 1978
- Kozhanchikov, 1950
- Mishin & Semevskii, 1971
- Schedl, 1936

Tunisia
- Rabasse & Babault, 1975
- Schedl, 1936

[3] Personal communication from L.R., Taylor, Rothamsted Experimental Station, Harpenden, Herts., England, May 17, 1978.

[4] Personal communication from H. Pschorn-Walcher, Commonwealth Institute of Biological Control, Delemont, Switzerland, June 30, 1978.

[5] Personal communication from U. Skatulla, Lehrstuhl für Angewandte Zoologie, Der Ludwig-Maximilians-Universitat, Munich, West Germany, July 27, 1978.

[6] Personal communication from R.P. Georgevits, Forest Research Institute, Athens, Greece, May 31, 1978.

[7] Personal communication from H. Pschorn-Walcher, Commonwealth Institute of Biological Control, Delemont Switzerland, Feb. 28, 1978.

[8] Personal communication from F. Herard, U.S.D.A., European Parasite Laboratory, Sevres, France, Nov. 17, 1978.

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